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A Dynamic Mission Replanning Testbed for Supervisory Control of Multiple Unmanned Aerial Vehicles

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14. ABSTRACT
As unmanned aerial vehicles (UAVs) increase in autonomy, operators will be increasing their span of control. Most UAV systems require two or more operators to fly and operate payloads, but systems are being developed with the concept of a single operator monitoring multiple UAVs. This supervisory control of multiple UAVs raises many issues concerning the balance of system autonomy with human interaction to keep the operator in-the-loop. Testbeds are needed that specifically address multi-UAV supervisory control, replicating the complex automation algorithms and allowing operator initiation and inspection into these systems. There is currently an effort underway to develop a dynamic mission replanning testbed for human factors research on supervisory control of multiple UAVs. This testbed utilizes Air Force certified autorouting study is being performed with this still developing testbed and results will be presented.

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Abstract

As unmanned aerial vehicles (UAVs) increase in autonomy, operators will be increasing their span of control. Most UAV systems require two or more operators to fly and operate payloads, but systems are being developed with the concept of a single operator monitoring multiple UAVs. This supervisory control of multiple UAVs raises many issues concerning the balance of system autonomy with human interaction to keep the operator in-the-loop. Testbeds are needed that specifically address multi-UAV supervisory control, replicating the complex automation algorithms and allowing operator initiation and inspection into these systems. There is currently an effort underway to develop a dynamic mission replanning testbed for human factors research on supervisory control of multiple UAVs. This testbed utilizes Air Force certified autorouting software and creates a tool to begin tackling issues many of these issues. A preliminary study is being performed with this still developing testbed and results will be presented.

Introduction

With advances in technology, unmanned aerial vehicles (UAVs) are becoming ever more self-sufficient. Some systems are already capable of completing entire pre-planned missions autonomously. Therefore, there is a logical progression to reduce the manpower required to operate each vehicle. This shift, from one or more operators flying and operating payloads on a single vehicle to one operator supervising multiple vehicles while managing other tasks, is complex. A major challenge is in determining the optimal involvement of the human operator at all times in all situations – how much of each task should be accomplished by the operator and how much should be accomplished by the automation? Also, the appropriate level of autonomy will likely vary from function to function and change depending on mission type and phase. Furthermore, with highly automated UAV systems, additional human factors issues to be considered include human vigilance decrements, "clumsy automation", limited system flexibility, mode awareness, trust/acceptance issues, failure detection, automation biases, etc. (Parasuraman & Mouloua, 1996; Gawron & Draper, 2001).

Research addressing the ideal balance of task allocation between the operator and UAV automated systems can benefit from testbeds designed to emulate the supervisory requirements of multi-UAV control. Some current testbeds include: UAV Modeling And Simulation Testbed (UMAST; Ruff, Narayanan, & Draper, 2002); Multi-Modal Immersive and Intelligent Interface for Remote Operation (MIIIRO; Ruff, Calhoun, Draper, Fontejon, & Guilfoos, 2004); Tactical Tomahawk Interface for Monitoring and Retargeting (TTIMR; Cummings, 2003); and, Multi-Aerial Unmanned Vehicle Experiment (MAUVE) interface (Cummings & Mitchell, in review). While each testbed has its strengths and weaknesses in terms of simulation fidelity, it is debatable whether current testbeds have sufficient underlying mission planning fidelity/complexity to adequately represent the supervisory control requirements anticipated for future multi-

UAV operations. This paper will explore testbed design requirements for multi-UAV applications as well as describe a new testbed under evaluation.

UAV Dynamic Mission Replanning: Human Factors Concerns

Dynamic mission replanning systems contain automation algorithms which allow missions to be modified in real-time. These modifications may occur in several main mission areas: allocation of tasks to vehicles; route replanning, sensor management, communications planning, and weapons management. Most of the current testbeds lack the complexity in automation and range of autonomy levels for multiple mission tasks. In one study utilizing the MIIRO testbed, for example, the route replanning automation logic was relatively simple and the human interaction with it required minimal cognitive effort (i.e., does the new route cross another UAV's route or enter a threat ring?). In the experiment, participants rushed to manually respond fast enough to avoid having the system automatically respond. Thus, for this experimental paradigm, automation was not a workload reducer (Ruff et al., 2004). The problem was not with the testbed per se, but with the complexity of the automation. This will not suffice for experimentation, as route replanners will need to process many complex and abstract variables simultaneously in order to generate new routes.

Future UAV operators must interact with highly complex systems, understanding critical pieces of information such as why the system chose a specific action, what criteria it used in making the decision, and what, if any, tweaking can be made to enhance mission success. The UAV operator's cognitive resources will be required to inspect the automation because algorithms operate on assumptions and will, at times, contain idiosyncrasies or have an incorrect model of the world state. With netcentric feeds and intelligent agents providing large amounts of data to the system, operators will be required to drill into the automation algorithms to investigate issues such as accuracy and recency of data used for decisions. However, if the interface to accomplish this inspection is not human factored, workload will increase. Additionally, inspection methods for these complex algorithms may not be straightforward, dependent upon the procedures used to ascertain new routes and task assignments. It is also important that the operator maintain overall situation awareness and attention not be tunneled on a specific inspection task. Therefore, researchers need to explore how best to design the interface by which an operator monitors and inspects automation for a multi-UAV system.

Though future UAV operators will interact with automation in a variety of ways, two of the most important will be the allocation of tasks among multiple UAVs and maneuvering of UAVs to achieve mission objectives. Nearly all events that occur in a multi-UAV environment will have an impact on task allocation and the routing of the aircraft, such as new threats or targets, changes in rules of engagement, changes in health and status of a vehicle, communication links, and weather. Moreover, the system must coordinate route planning with sensor requirements, ingress/egress paths, aircraft deconfliction, and pre-defined aircraft operating areas and altitudes. These complexities require a testbed that more fully replicates dynamic mission replanning. An effort is underway to develop a testbed that enables user interaction with a high fidelity dynamic mission replanning system and employs adaptive levels of automation.

The ALOA Testbed

The Adaptive Levels of Automation (ALOA) testbed is a multi-UAV mission control station emulator (MCSE) being developed as part of the Air Force Research Laboratory's program to address human factors associated with multi-UAV operator control stations. This UAV operator/automation research testbed is unique in that it incorporates a commercially available dynamic mission replanner, increasing the testbed's complexity and realism (Johnson, Leen, Goldberg, & Chiu, 2005).

The backbone for the ALOA MCSE testbed is Operations Research Concepts Applied's (ORCA) OPUS software. Used for mission planning, OPUS specializes in autorouting tools for low-observable aircraft. OPUS is certified for operational use by the Air Force and endorsed by the Navy's UAV Advanced Technology Review Board. By means of vehicle-threat interaction models, OPUS takes into account vehicle radar cross section data and radar vertical coverage diagram data. These tools and models provide the ALOA MSCE testbed with a realistic operational mission planning environment.

Besides its high fidelity routing abilities, this testbed will also incorporate both adaptable and adaptive levels of automation for a variety of operator tasks. Through adaptable automation, operators actively change the current level of system autonomy for each task. The adaptable automation can also be grouped into predefined autonomy levels for each task, much like a stereo equalizer, allowing an operator to pick a broad "scheme" autonomy. However, the task of changing autonomy levels can quickly become an additional burdensome task for the operator. One solution is to combine the components of an adaptable system with those of an adaptive system. In adaptive automation, the system initiates changes in the autonomy level based on: 1) real-time measurement of the operator's performance on tasks; 2) current mission profile and sensed events; and, 3) the operator's physiological measurements. The ALOA MSCE plans to incorporate all of these controls and allow for plug-in physiological metric inputs. This will enable the examination of how adaptive automation (the computer actively changing autonomy levels) can help the operator maintain a manageable workload level, while preserving his/her situation awareness.

The ALOA system is still undergoing development. However, an experiment is currently underway with an early version of the system to obtain a preliminary assessment of autonomy levels in an operator route selection task, as well as to evaluate the functioning of the ALOA testbed and identify needed refinements.

Preliminary ALOA Study

This study is manipulating the number of UAVs under control (1, 3, or 4) and three autonomy levels of the auto-routing. In the multiple options autonomy level, the participants are presented with the current route and two modified routes. The consent autonomy level presents the operator with a single route but requires operator consent before implementing. The automatic with feedback autonomy level notifies the operator after the computer has selected and implemented a route (but does not allow a veto option). Using a within-subjects design, each participant completes 18 randomized eight-minute trials (3 UAV levels X 3 autonomy levels X 2 repetitions).

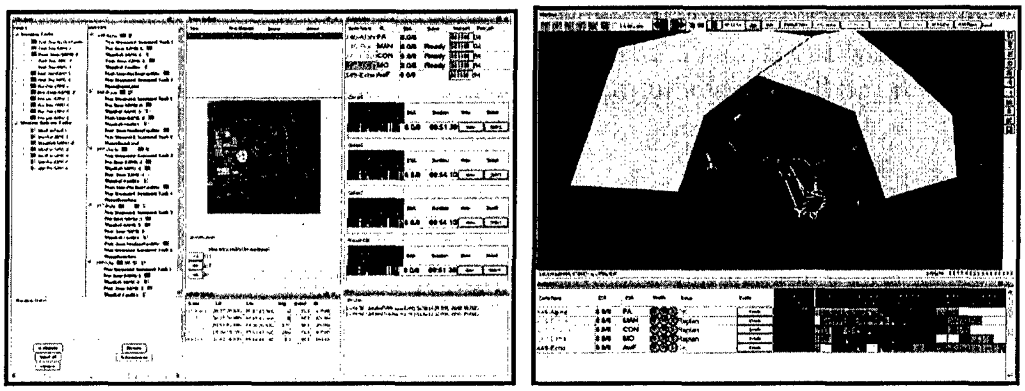

Figure 1. ALOA's dual screen layout.

The ALOA testbed utilizes a dual screen layout (see Figure 1). Participants use the left monitor to perform image identification and weapon release tasks, monitor chat, allocate tasks, replan routes, and access vehicle data such as current location coordinates. The right monitor contains the tactical situation display, health and status display, current route information, and other response buttons. While monitoring one or more vehicles performing a suppression of enemy air defense (SEAD) mission, participants perform several different tasks: respond to unidentified aircraft; replan vehicles when new threats appear; monitor the health and status of vehicles; identify incoming images; and, answer Situation Awareness Global Assessment Technique (SAGAT) questions when the simulation is paused. This experiment is underway, and full results will be presented at the conference.

Future Research Directions

There exist a myriad of issues surrounding operator inspection of complex routing and task assignment algorithms. For example, dynamic replanning can be very time dependent. The amount of time available to react will dictate the type of replanning initiation and inspection that is possible. Short-reaction threats may require automatic evasive maneuvers and replans. Over longer periods, more operator involvement in replan inspection is possible, but it has yet to be determined how beneficial human intervention will be. Design factors such as the amount of time given to the operator to replan, what information should be most readily available, and how the automation should play into those replans need to be examined.

Future studies will also be required to examine automation bias, adaptive and adaptable levels of automation, automation schemes, and scenarios with changing rules of engagement. While the ability to study unreliable automation in the routing is possible with the ALOA simulator, the concept of reliable automation lacking all necessary information is a particular area of interest. This will be accomplished by changes in the rules of engagement through the chat window. For example, the routing software will calculate what it considers the best route based on the given parameters for fuel economy, threat avoidance, etc. However, based on the most recent rules of engagement, the operator has been directed to strike a target regardless of threat exposure. In this case, the automation is not incorrect but simply lacking in all the latest contextual information. The automation is only as good as the information it can access.

Due to the complexity of the automation algorithms, it is difficult to decide which inputs to display to the operator. Autorouting, for instance, considers vehicle performance, threat susceptibility, and terrain parameters to determine a feasible route that achieves mission objectives. Within those considerations, there are numerous parameters that can be adjusted to alter the output. Breaking down which components to display to the operator and which to allow to be manipulated are other questions that require further research. With the flexibility of the ALOA MSCE testbed, it will be possible to explore issues such as these.

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